Produced by Design and Local Programs,
Office of State Geometric Design Standards

Getting Into Metrics

A Metric Primer

Caltrans
Metric

Fourth Edition

Let's Get Metric

Welcome to the world of the metric system, or the International System of Units, often abbreviated as "SI". Caltrans has the privilege of leading California into this world.

Actually, the metric system has been around for more than two centuries. Benjamin Franklin and Thomas Jefferson first proposed that the US convert to the metric system, but it was more than two hundred years before another president, George Bush, in 1991, would sign an executive order to mandate that all agencies using federal money begin using the standard.

That's how we got into it. FHWA responded to President Bush's order by developing a plan requiring that all agencies using federal highway dollars begin advertising projects for construction using metric units by October 1, 1996. Although the federal mandate has been postponed until the year 2000, Caltrans has maintained its schedule based on the original 1996 deadline. This booklet is a part of the Caltrans response to the federal mandate.

Actually, for a technical agency like Caltrans, metricating shouldn't be such a big deal. Most of our engineers were trained in the metric system in college. Our surveying equipment is already in metric and has to convert back to US units to make the data available. And most engineers prefer to work with orderly and systematic systems.

An international standard, called "ASTM E380", provides guidelines for the proper use of SI. Caltrans has adopted that standard, except that we use the American spelling of "liter" and "meter", rather than the French "litre" and "metre". This booklet, drawing on ASTM E380, contains basic information for your use in doing your job. That's why we call it a "primer". It contains basic descriptions of the units, conventions for writing the terms, and conventions for rounding and converting from the US system.

The Metric Symbol

This is the Caltrans Metric Symbol. Its purpose is to make it clear immediately that a Caltrans document is using metric units. It should be placed in a prominent spot on all metric documents, including the following:

Plans
Project Reports
Project Study Reports
Project Approval Reports
Drainage Reports
Materials Reports
Noise Barrier Scope Study Reports
Structural Section Recommendation Reports
Design Exceptions from Mandatory Standards
Preliminary Reports
Bridge Site Data
Bridge Inspection Reports
Geotechnical Reports
Engineering Geology Reports
Reports issued by the Transportation Laboratory
Environmental Impact Reports
Negative Declarations
Categorical Exemption Reports
Traffic Reports

This is not an exhaustive list. You should also use it in materials which pertain directly to the metric conversion or any other report or document in which units are expressed in the metric system.

Your Basic Metric Stuff

The neatest thing about the Metric System is that all units are based on decimal mathematics. A kilometer is 1000 meters and a kilogram is 1000 grams (you'll understand later why there are no commas). No more eight pints to the gallon or 5,280 feet to the mile. No mils, inches, feet, yards, fathoms, rods, chains, furlongs, or miles. Here are some basics:

Meter (m): The basic measure of distance in the Metric System, a little longer than a yard.

Kilometer (km): The basic measure of longer distances, a little longer than a half-mile.

Millimeter (mm): For measuring the little stuff (a dime is about a millimeter thick). There's a centimeter too -- about a third of an inch -- but Caltrans won't measure in centimeters.

Liter (L): The Metric System's basic measure of liquid, a little larger than a quart.

Gram (g): For weighing the little stuff. A paper clip weighs about a gram.

Kilogram (kg): One thousand grams, weighing a little more than two pounds. The **tonne** or metric ton, about the weight of a fast sports car (1000 kilograms), is used for larger weights.

Time (s): The second, the basic measure of time, remains the same as in the US system.

Ampere (A): The basic measure of electric current, same as in the US system.

Candela (cd): The basic measure of luminosity.

Temperature (K): The basic measure of temperature. Celsius temperature (°C) is used more commonly than kelvin (K), but both have the same temperature gradients. Celsius temperature is just 273.15 degrees warmer than kelvin, which begins at absolute zero. Water freezes at 273.15 K and at 0°C. To move between Celsius and kelvin, add or subtract 273.15.

The **radian (rad)** and **steradian (sr)** denote plane and solid angles. They are used in lighting work and in various engineering calculations. In surveying, the units **degree (°), minute (')** and **second (")** continue in use.

Terminology

Special Names

Measurable Attribute	Unit	Symbol	Expression
Frequency of periodic phenomena	hertz	Hz	Hz = s^{-1}
Force	newton	N	N = kg•m/s^2
Energy/work/quantity of heat	joule	J	J = N•m
Power, radiant flux	watt	W	W = J/s
Pressure/stress	pascal	Pa	Pa = N/m^2
Celsius temperature	degree Celsius	°C	
Quantity of electricity	coulomb	C	C = A•s
Electric potential	volt	V	V=W/A or J/C
Electric resistance	ohm	Ω	Ω = V/A
Luminous Flux	lumen	lm	lm = cd•sr
Luminance	lux	lx	lx = lm/m^2

Derived Units

Measurable Attribute	Unit	Expression
Acceleration	meter per second squared	m/s^2
Area	square meter hectare (10 000 m^2)	m^2 ha
Density/mass	kilogram per cubic meter	kg/m^3
Luminance	candela per square meter	cd/m^2
Pressure/Stress	newtons per square meter	N/m^2
Velocity	meter per second	m/s
Volume	cubic meter	m^3

Multiplication Factors

Multiple	Prefix	Symbol
1 000 000 000 = 10^9	giga	G
1 000 000 = 10^6	mega	M
1 000 = 10^3	kilo	k
100 = 10^2	*hecto	h
10 = 10^1	*deka	da
0.1 = 10^{-1}	*deci	d
0.01 = 10^{-2}	*centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	µ
0.000 000 001 = 10^{-9}	nano	n

* avoid where possible

Recommended Pronunciations

Prefix	Pronunciations
giga	jig' a (*i* as in j*i*g, *a* as in *a*-bout)
mega	as in *mega*-phone
kilo	kill' oh
hecto	heck' toe
deka	deck' a (*a* as in *a*-bout)
deci	as in *deci*-mal
centi	as in *centi*-pede
milli	as in *mili*-tary
micro	as in *micro*-phone
nano	nan' oh (*an* as in *an*t)

Drafting Standards for Metric Plans

- Sheet sizes shall remain the same size until the paper manufacturers begin producing paper in metric sizes. At that time, the Department will adopt the ISO “A” series of paper sizes.
- Stationing shall be based on 100 meters per station. Because 100 meters is such a large distance, station tick marks will be at 20 m intervals with annotation at full 100 m stations.
- The Post Mile System will be soft converted to the Kilometer Post System (KP) by applying the 1.6093 conversion factor to the existing system. All equations and prefixes will be retained.
- Scales

Plan Sheets:

Imperial Scale	Metric Scale	Grid Tick Interval
1" = 1'	1:10	
$\frac{3}{4}$" = 1'	1:20	
$\frac{1}{2}$" = 1'	1:20	
$\frac{3}{8}$" = 1'	1:50	
$\frac{1}{4}$" = 1'	1:50	
1" = 2'	1:20	
1" = 5'	1:50	
1" = 10'	1:100	
1" = 20'	1:200	50 m
1" = 40'	1:500	100 m
1" = 50'	1:500 (urban)	100 m
1" = 100'	1:1000 (rural)	200 m
1" = 200'	1:2000	500 m
1" = 400'	1:5000	1000 m

Crosshair legs shall be 20 mm long (actual plan dimension).

Drafting Standards for Metric Plans (cont.)

Profile Sheets:

- Rural sections in hilly or mountainous terrain - 1:100 vertical, 1:1000 horizontal
- Rural or urban with gentle rolling terrain - 1:50 vertical, 1:500 horizontal
- Rural or urban with level terrain - 1:20 vertical, 1:200 horizontal

Cross Sections:

- Rural - 1:100
- Urban - 1:50

- Pavement cross slope and superelevation shall be shown as percent.
- Angular measurement shall retain Degree-Minute-Second convention.
- Cross section intervals shall be 20 m, or as required.
- Contour intervals:

Scale	Index Contours	Intermediate Contours
1:200	1 m	0.25 m
1:500	2 m	0.5 m
1:1000	5 m	1 m
1:2000	10 m	2 m
1:5000	25 m	5 m

- All survey information shall be expressed in meters. Output of survey information on Right of Way maps showing property data should be expressed in meters, square meters or hectares. Where record data is included, it shall be expressed in its original units.

Drafting Standards for Metric Plans (cont.)

- Dual units shall not be allowed on construction plans.

- Side slopes shall be expressed in nondimensional ratios. The vertical component is shown first and then the horizontal (Y:X). This is the opposite of existing convention, but consistent with normal math practices and also adopted by AASHTO. For slopes less than 45°, the vertical component shall be unitary (for example, 1:20). For slopes over 45°, the horizontal component shall be unitary (for example, 5:1) since the metric system does not use fractions.

- In general, dimensions smaller than 1 m should use millimeters. Dimensions greater than 1 m should be expressed as meters except if the English unit was traditionally shown in inches. If so, use millimeters. Pipes, structural sections, railings and roadside sign panels will all be shown in millimeters.

- The metric logo is to be used on all documents using the metric system. On plan sheets the 30 mm x 30 mm size logo shall be placed immediately left of the signature block.

- For additional information on drafting standards for metric plans, refer to the Caltrans Drafting and Plans Manual 1996 available through the Caltrans Publication Unit.

Writing Conventions

- **Use upright text**

  Correct: *Bob is running in tomorrow's* **10 km** *race*.
  Incorrect: *Bob is running in tomorrow's **10 km** race.*

- **Plural same as singular**

  Correct: To train for the **10 km** race, Bob runs 1 km a day.
  Incorrect: To train for the **10 kms** race, Bob runs 1 km a day.

- **No period follows (except end of sentence)**

  Correct: After the **10 km** race, Bob will walk 1 km.
  Incorrect: After the **10 km.** race, Bob will walk 1 km.

- **Use lower-case (except for symbols derived from a proper name):**

Unit	Symbol:
meter	m
millimeter	mm
kilometer	km
kilogram	kg
liter	L *
Celsius	°C
newton	N
joule	J

*The symbol "L" is recommended for liter in the United States, although both "L" and "l" are approved alternative symbols, since the letter l can easily be confused for the numeral 1. Written out, "Celsius", also an exception, uses capital "C".

- **Space Between Digit Number and Unit Symbol**

  Correct: 35 mm
  or 250 kg
  Incorrect: 35mm
  or 250kg
  Exceptions: 45˚ and not 45 ˚
  20˚C and not 20˚ C

Conventions (cont.)

- **No Space Between Prefix or its Symbol and Unit**

Correct:	megapascal	MPa
Incorrect:	mega pascal	M Pa

- **With Symbols:**

  Use Raised Dot for Product:

  N· m for newton meter

  Use Slash or Solidus for Quotient:

  m/s or $\mathbf{m\cdot s^{-1}}$ or $\frac{m}{s}$ for meters per second

- **With Unit Names**

  Use Space or Hyphen for Product:

Correct:	newton meter, or newton-meter
Incorrect:	newtonmeter
Exception:	watthour

  Use "per" for Quotient (not /):

Correct:	meter per second
Incorrect:	meter/second

- **Fractions Unnecessary**

  Correct: 2.5 m
  Incorrect: $2\frac{1}{2}$ m

- **Use Zero before Decimal Marker**

  Correct: 0.1234
  Incorrect: .1234

Conventions (cont.)

- **Spell out the unit only when the number is spelled out**

  Correct: 10 m or ten meters
  Incorrect: 10 meters or ten m

- **Group digits by three from decimal point. Use a "hard" space, *not* a comma** (refer to your software manual to avoid end-of-line separations) **to separate the digits**.

US	International (metric)
26,345	26 345
2.141596	2.141 596

  In numbers with FOUR digits on either side of the decimal a space is not necessary except for uniformity in tables.

  Correct: 0.1335 kg or 2345 kg
  Incorrect: 0.133 5 kg or 2 345 kg

- **Until CADD software is modified to display numbers with spaces in lieu of commas, it is acceptable to display numbers or CADD drawings continuously without spaces or commas.**

  Preferred: 123 456.789 01
  Acceptable: 123456.78901
  Not Acceptable: 123,456.78901

- **Monetary values will continue to be expressed in the traditional manner.**

  Correct: $725,000.00
  Incorrect: $725 000.00

Common Conversion Factors to Metric

Class	Multiply:	By:	To Get:
Area*	ft^2	0.0929	m^2
	yd^2	0.8361	m^2
	mi^2	2.590	km^2
Length*	ft	0.3048	m
	in	25.4	mm
	mi	1.6093	km
	yd	0.9144	m
Volume	ft^3	0.0283	m^3
	gal	3.785	L **
	fl oz	29.574	mL **
	yd^3	0.7646	m^3
	acre ft	1233.49	m^3
Mass	oz	28.35	g
	lb	0.4536	kg
	kip (1,000 lb)	0.4536	tonne(1000kg)
	short ton (2,000 lb)	907.2	kg
	short ton	0.9072	tonne(1000kg)
Density	lb/yd^3	0.5933	kg/m^3
	lb/ft^3	16.0185	kg/m^3
Pressure	psi	6894.8	Pa
	ksi	6.8948	MPa (N/mm^2)
	lb_f/ft^2	47.88	Pa
Velocity	ft/s	0.3048	m/s
	mph	0.4470	m/s
	mph	1.6093	km/h
Light	footcandle (or) $lumen/ft^2$	10.764	lux (lx) (or) $lumen/m^2$
Temperature	°F	$t_{°C} = (t_{°F} - 32)/1.8$	°C

* For land surveying, see "Land Surveying Conversion Factors" table on page 13

** Use Capital "L" for liter to eliminate confusion with the numeral "1"

Land Surveying Conversion Factors

Class	Multiply :	By:	To Get
Area	acre	4046.872 61	m^2
	acre	0.404 69	ha (10 000 m^2)
Length	ft	1200/3937*	m

* Exact, by definition of the US Survey foot, Section 8810, State of California Public Resources Code

Less Common Conversion Factors

Class	Multiply:	By:	To Get:
Density: Gravity Force	lb_f/ft^3	157.0	N/m^3
	lb_f/in^3	271.0	kN/m^3
	kg_f/m^3	9.81	N/m^3
Density: Mass	lb_m/in^3	27.68	Mg/m^3
	lb_m/gal (US)	119.8	kg/m^3
Force (including gravity force)	dyne	0.01	mN
	kg_f	9.81	N
	oz_f	0.278	N
	lb_f	4.45	N
	ton_f (2000 lb_f)	8.90	kN
Mass	carat (metric)	0.2	g
	oz_m (avoirdupois)	28.35	g
	oz_m (troy)	31.10	g
	lb_m	0.454	kg
	slug	14.6	kg
	ton_m (short)	0.907	Mg

Note: The Metric System eliminates the confusion in US terminology about "weight" by separating it into two definitions: "mass", and "gravity force". Mass refers to the inertia of an object, or the force required to accelerate or decelerate it in a gravity-free environment. Gravity force is the net downward force acting on a stationary object to attract it to another, always proportional to the strength of the gravitational field and the object's mass.

Conversion and Rounding

General

- Conversion from US to SI may be either exact ("soft"), or a suitable approximation ("hard").
- In a **soft** conversion, the US unit is converted to an **exact** metric equivalent.
- In a **hard** conversion, the US unit is converted to a **new rounded, rationalized metric number** convenient to work with.
- In all conversions, use SI equivalents similar in magnitude to the original. If a 1/16 inch scale was suitable for the original measurement, a 1 mm metric scale is suitable for the conversion.

Conversions

- Always establish intended precision as a guide to how many digits to retain after conversion. The number 1.1875 may be a very accurate decimalization of a number that could have been expressed as 1.19. The value 2 may mean "about 2," or it may be a very accurate value of 2, expressed as "2.0000".
- The converted dimension should be rounded to a minimum number of significant digits so the unit of the last place is equal to or smaller than its conversion.

  Example:

  Precision of a 6 inch stirring rod is estimated at about $\frac{1}{2}$ in ($\pm \frac{1}{4}$ in) or, converted, 12.7 mm. The converted dimension, 152.4 mm, should be rounded to the nearest 10 mm and shown as 150 mm.

- Converted values should be rounded to the minimum number of significant digits in order to maintain the required accuracy.

  Example:

  A length of 125 ft converts exactly to 38.1 m. But if the 125 ft length was obtained by rounding to the nearest 5 ft, the conversion should be given as 38 m; if it had been obtained by rounding to the nearest 25 ft, the result should be rounded to 40 m.

Conversion and Rounding (cont.)

- A stated limit such as "not more than" must be handled so the limit is not violated. "At least 3 inches wide" requires a width of at least 76.2 mm, or at least 77 mm.

- When converting, multiply a value by a more accurate factor than required, then round appropriately afterward. Rounding before multiplying will reduce accuracy.

  Example:

  When converting 3 feet 2 $\frac{9}{16}$ inches to meters ($\frac{9}{16}$ " = 0.5625"):
  (3 x 0.3048)+(2.5625 x 0.0254) = 0.979 487 5 m, rounds to 0.979 m

Significant Digits

- When converting integral values of units, consider the implied or required precision of the integral value to be converted.

  Example:

  The value "4 in." may represent 4, 4.0, 4.00, 4.000 or 4.0000 in.

- Any digit necessary to define the specific value or quantity is significant.

  Example:

  Measured to the nearest 1 m, a recorded distance of 157 m would have three significant digits. Measured to the nearest 0.1 m, a distance of 157.4 m would have four significant digits.

- Zeros may indicate either a specific value or an order of magnitude. As an example, the population of the United States in 1970, rounded to thousands, was 203 185 000. The six left-hand digits are significant, each measuring a value. The three right hand zeros indicate that the number has been rounded to the nearest thousand.

Conversion and Rounding (cont.)

- Identifying significant digits is only possible by knowing the circumstances by which they were originally arrived at. For example, if the number 1000 is rounded from 965, only one zero is significant. If it is rounded from 999.7, all three zeros are significant.

- When adding or subtracting, the answer must contain no significant digits to the right of the least precise number.

Example:

For the problem:	Round the numbers one significant digit to the right of the least precise number and take the sum as follows:
163 000 000	163 000 000
217 885 000	217 900 000
96 432 768	96 400 000
477 317 768	477 300 000

(Round the total to 477 000 000 as called for by the rule)

- When multiplying or dividing, the product or quotient must contain no more significant digits than the fewest significant digits used in the multiplication or division.

Example:

113.2 x 1.43 = 161.876 -- round to 162 because 1.43 has three significant digits

113.2 ÷ 1.43 = 79.160 8 -- round to 79.2 for same reason.

Conversion and Rounding (cont.)

Rounding Values

- When the first digit discarded is less than 5, the last digit retained is not changed.

  Example:

  3.463 25, rounded to four digits would be 3.463; if rounded to three digits, 3.46.

- When the first digit discarded is greater than 5 or is a 5 followed by at least one digit other than 0, add 1 to the last digit retained.

  Example:

  8.376 52, rounded to four digits would be 8.377; if rounded to three digits 8.38.

- When the first digit discarded is exactly 5 followed only by zeros, the last digit retained should be rounded upward if it is odd. No adjustment is made if it is an even number.

  Example:

  4.365, rounded to three digits becomes 4.36. The number 4.355 would round to the same value, 4.36, if rounded to three digits.

This Primer is provided by:

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For other useful information concerning Caltrans metrication visit the Caltrans metric website located at:

http://www.dot.ca.gov/hq/oppd/metric/metricprg.html

Other Metric documents are available through:

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Drafting and Plans 1996	*$22.00*

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